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Okazawa et al.

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(54) **IMAGE PROCESSING DEVICE, IMAGE PROCESSING METHOD, AND IMAGE PROCESSING PROGRAM**

(58) **Field of Classification Search**  
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See application file for complete search history.

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(57) **ABSTRACT**

(51) **Int. Cl.**  
**G06T 7/33** (2017.01)  
**G06T 5/00** (2006.01)

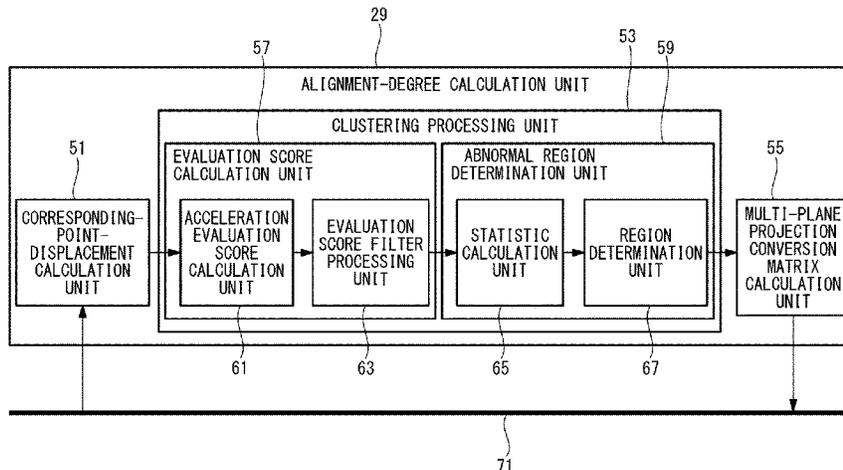
(Continued)

An image processing device includes circuitry configured to: calculate a displacement of each of a plurality of corresponding feature regions between a reference image and a base image; calculate, as an evaluation score, difference value between displacements of two feature regions adjacent to each other in at least one of the up/down direction, the left/right direction, and the oblique 45° direction; determine an abnormal region on the basis of the score; classify other feature regions excluding the abnormal feature region; calculate a projection conversion matrix by using the displacement of the other feature regions and the result of the classification; calculate a degree of alignment of each pixel

(Continued)

(52) **U.S. Cl.**  
CPC ..... **G06T 7/33** (2017.01); **G06T 5/002** (2013.01); **G06T 5/50** (2013.01); **H04N 5/23229** (2013.01);

(Continued)



of the reference image with respect to each pixel of the base image by using the matrix; and generate a combined image by combining the reference image converted based on the degree of alignment with the base image.

**8 Claims, 13 Drawing Sheets**

- (51) **Int. Cl.**  
*G06T 5/50* (2006.01)  
*H04N 5/232* (2006.01)
- (52) **U.S. Cl.**  
 CPC ..... *G06T 2207/10016* (2013.01); *G06T 2207/20182* (2013.01); *G06T 2207/20221* (2013.01)

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Written Opinion of the International Searching Authority dated Aug. 29, 2017 issued in International Application No. PCT/JP2017/019930.

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FIG. 1

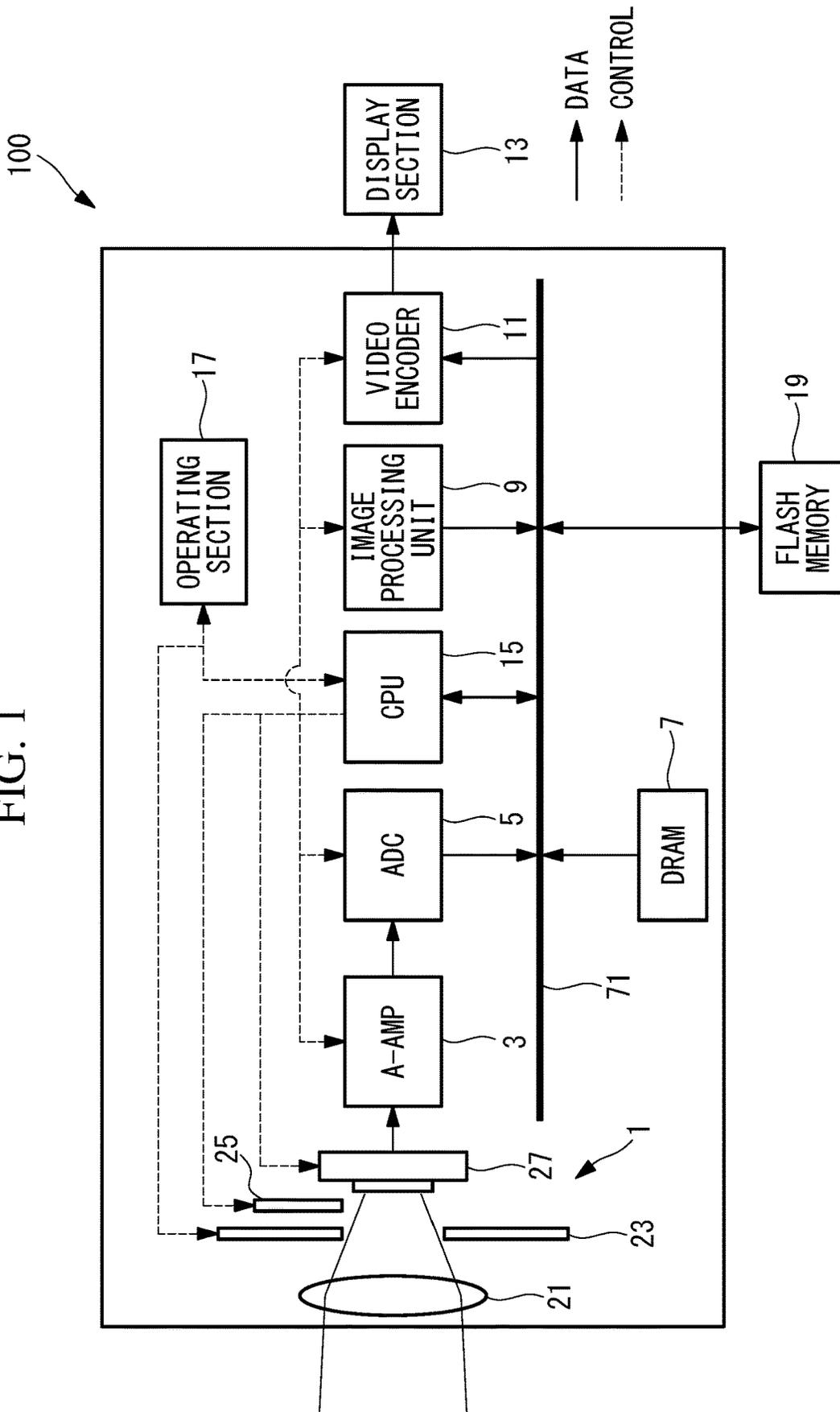


FIG. 2

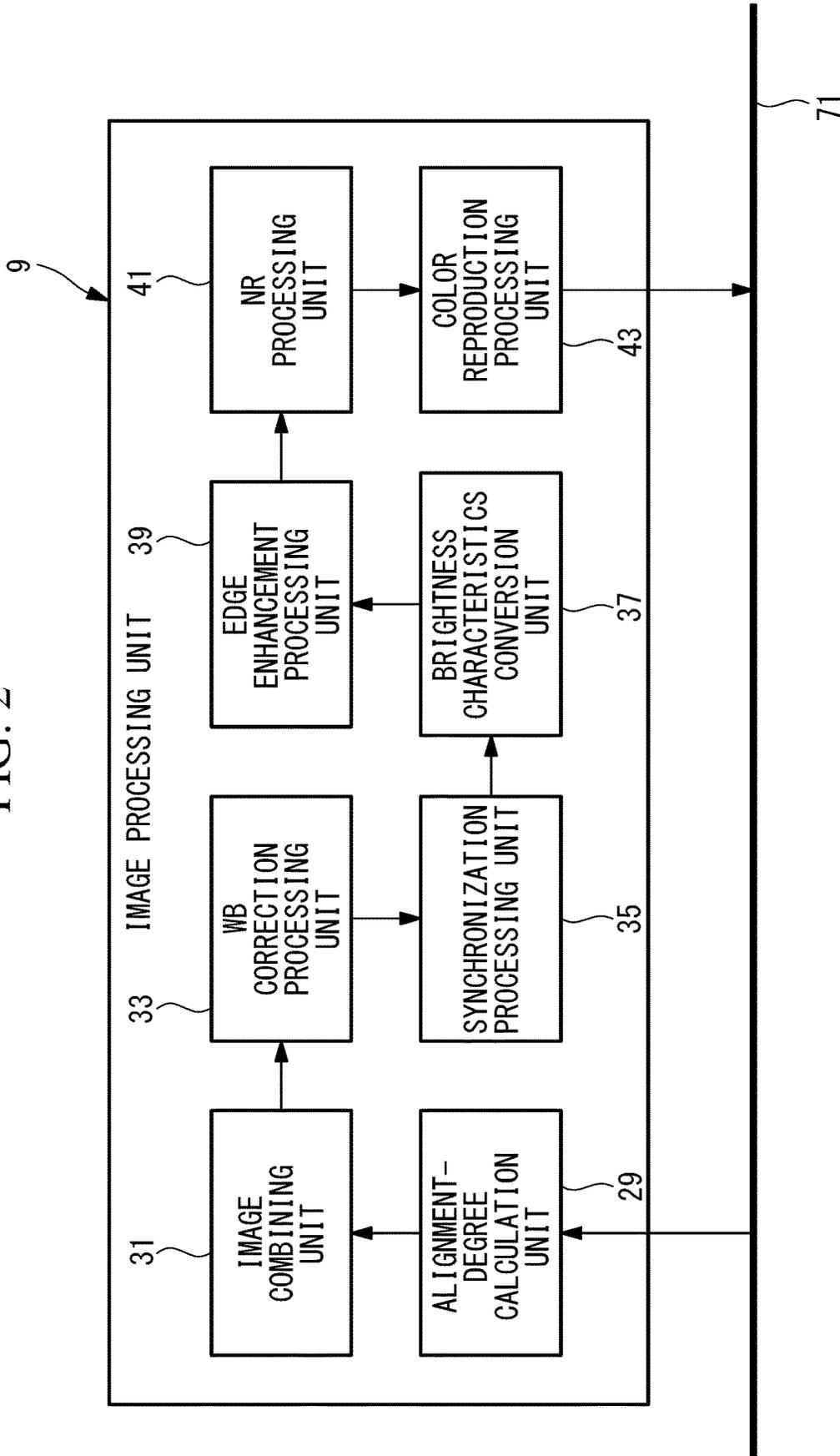


FIG. 3

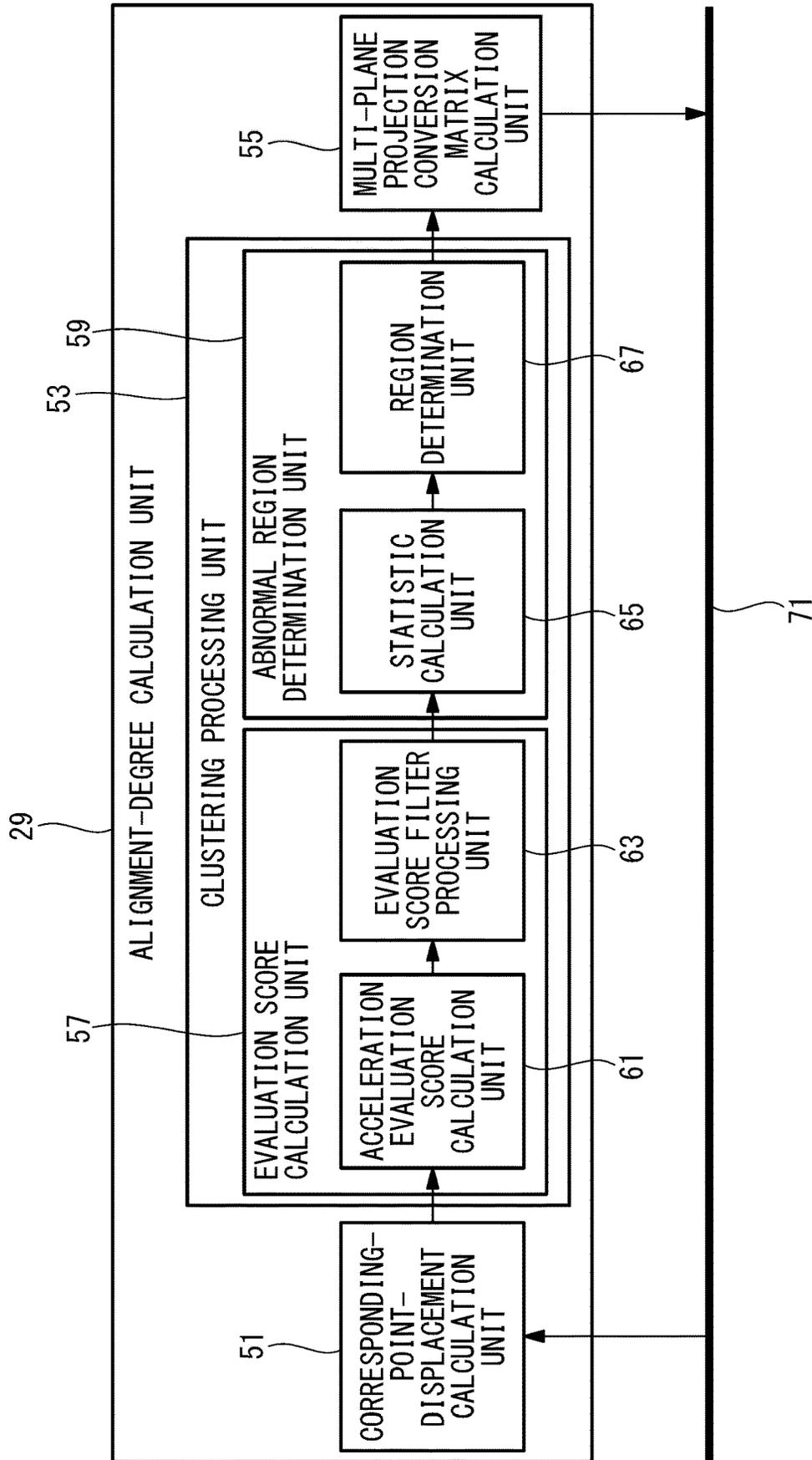


FIG. 4A

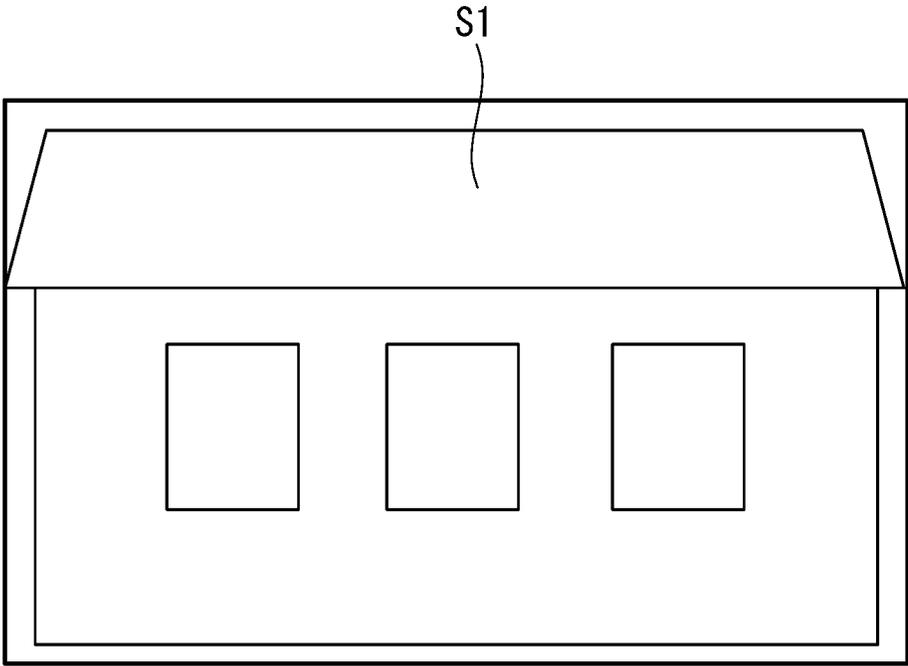


FIG. 4B

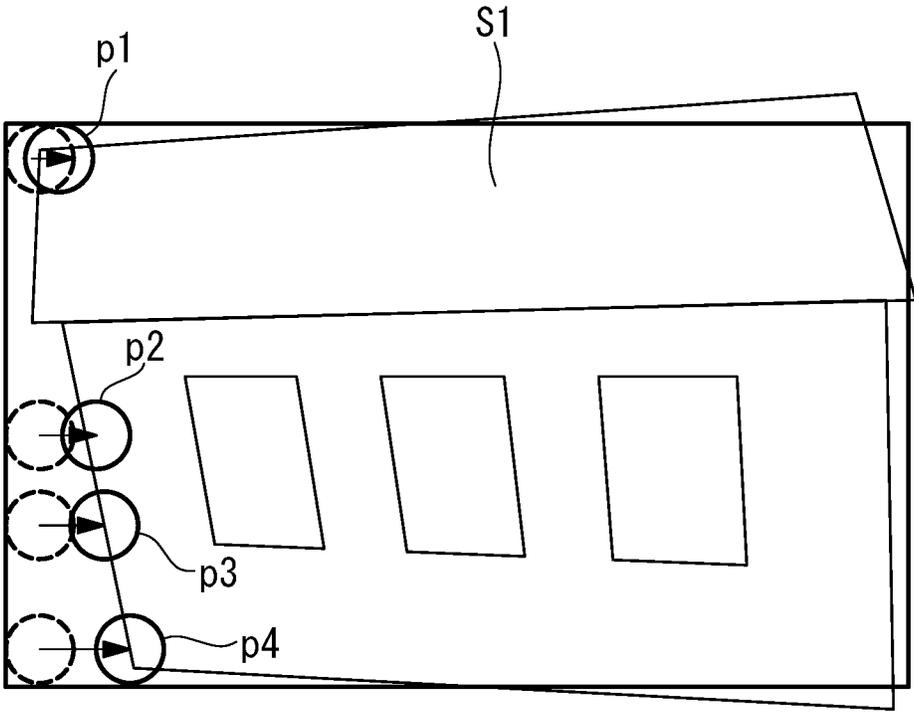


FIG. 5A

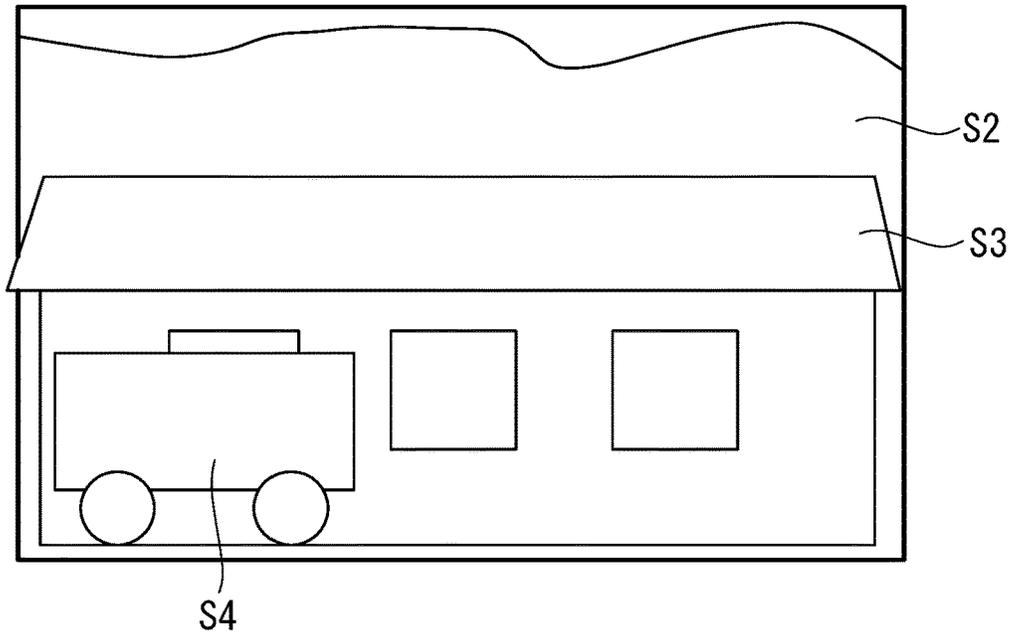


FIG. 5B

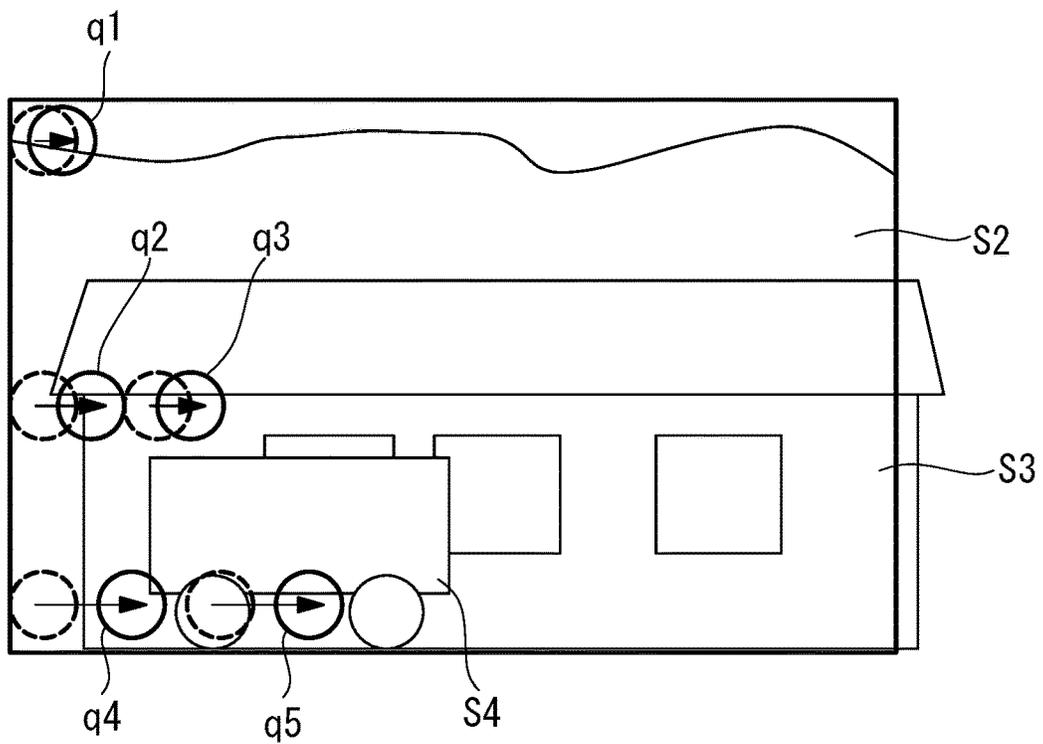


FIG. 6A

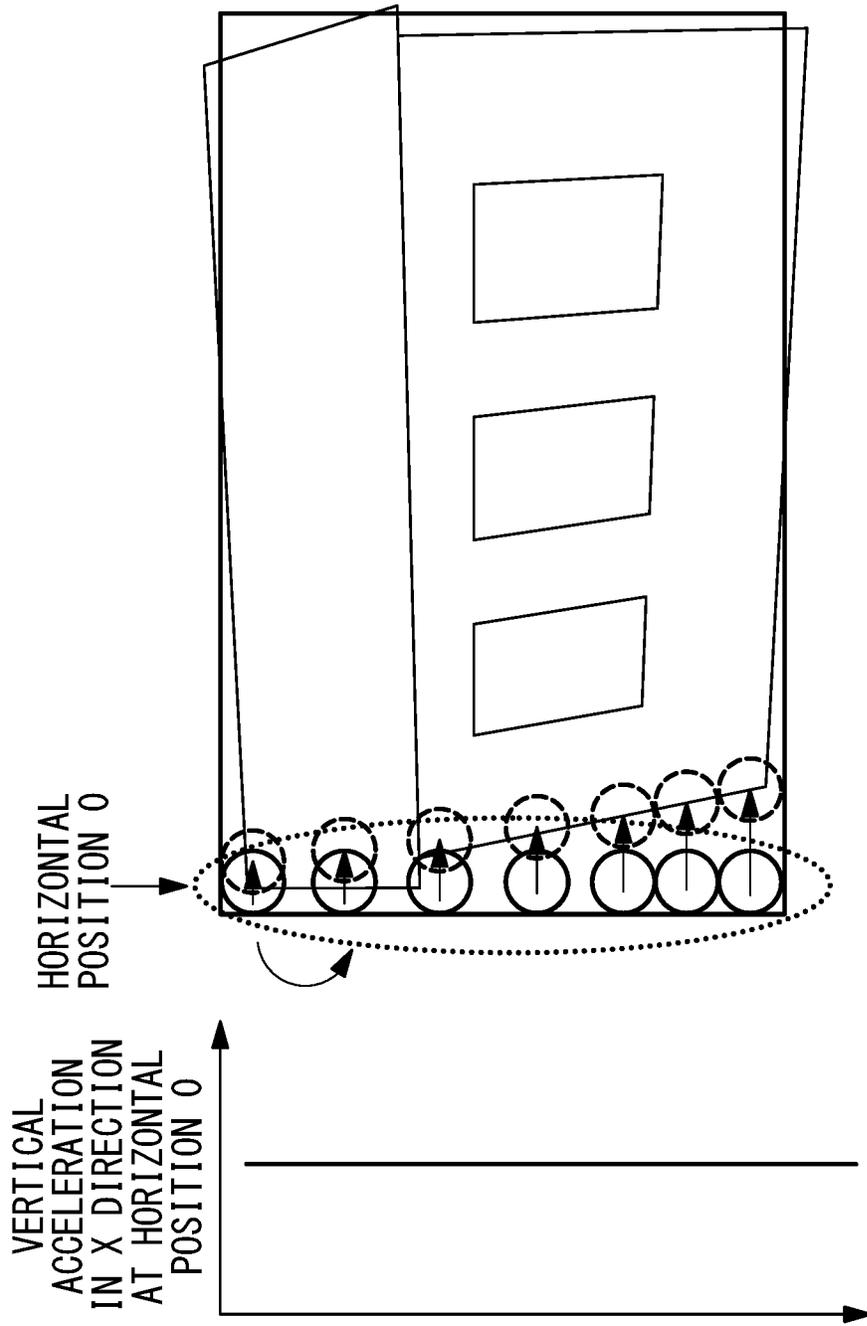


FIG. 6B

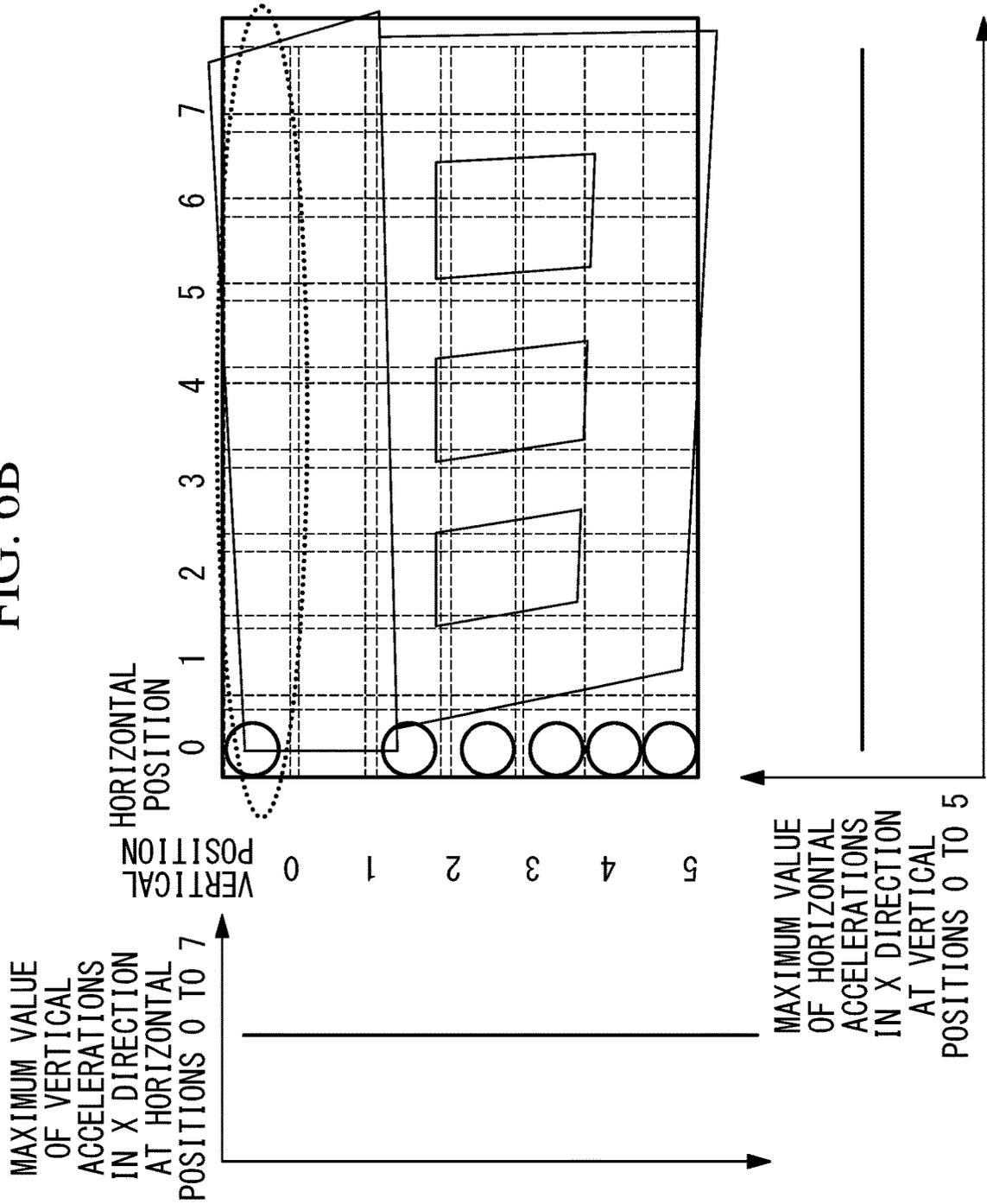


FIG. 7A

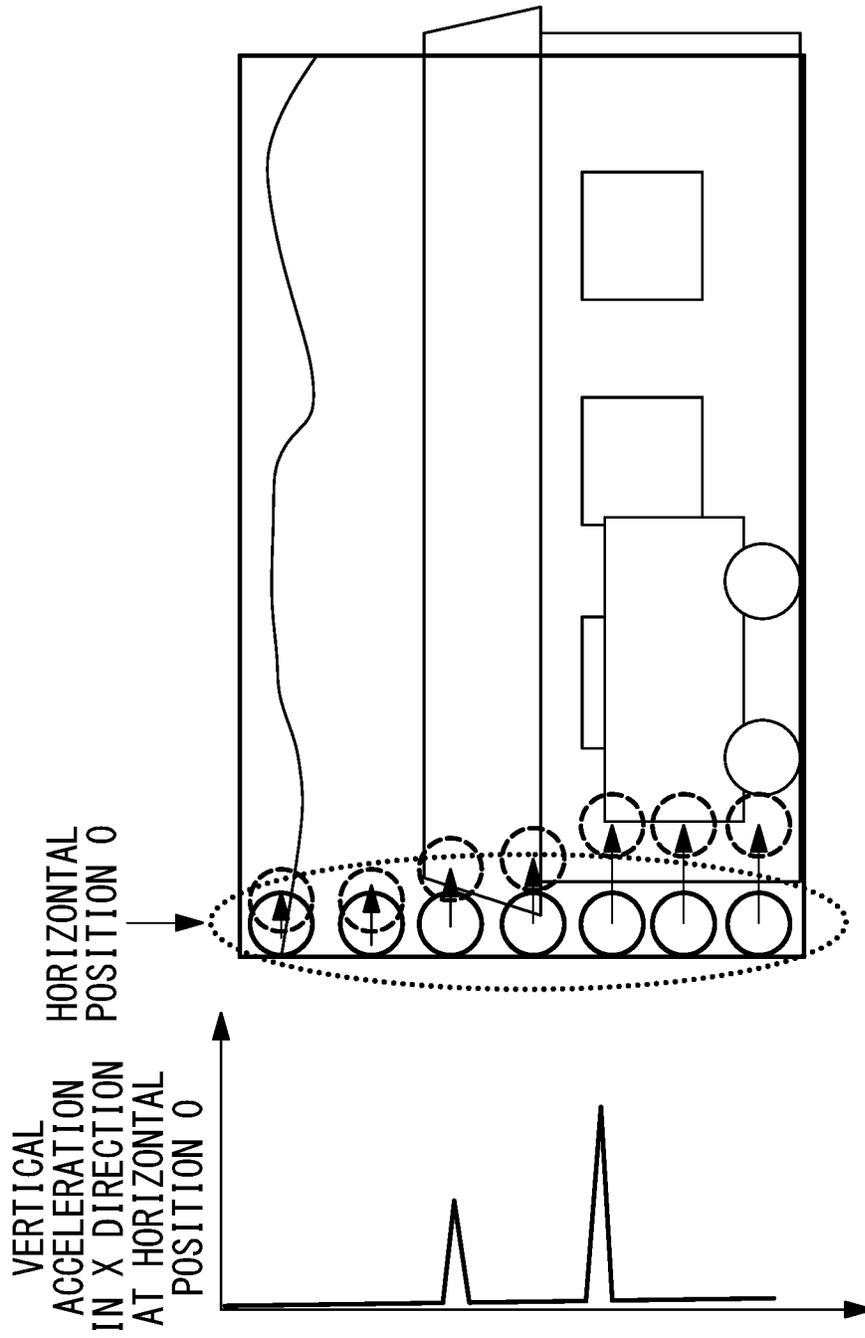


FIG. 7B

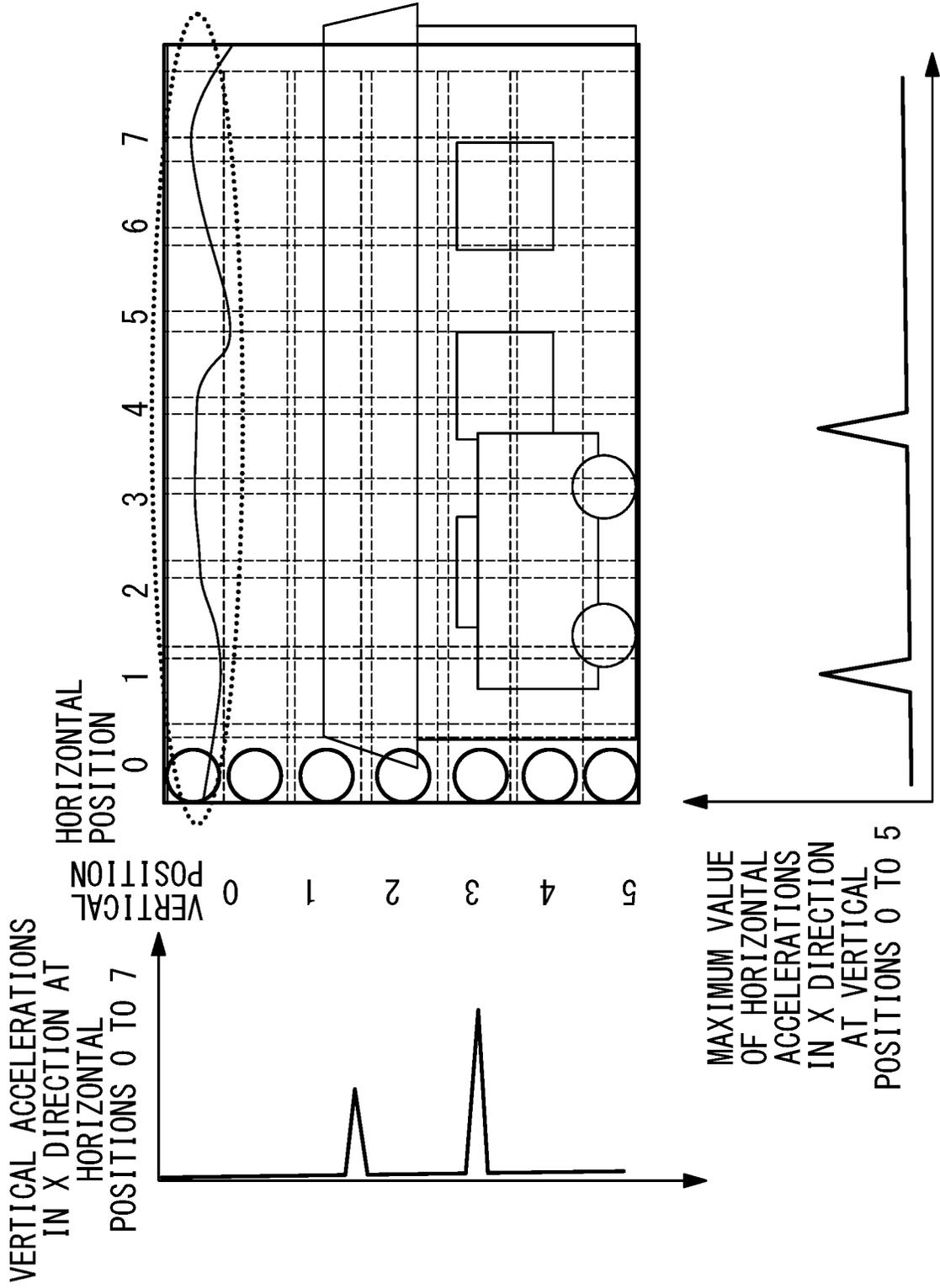


FIG. 8A

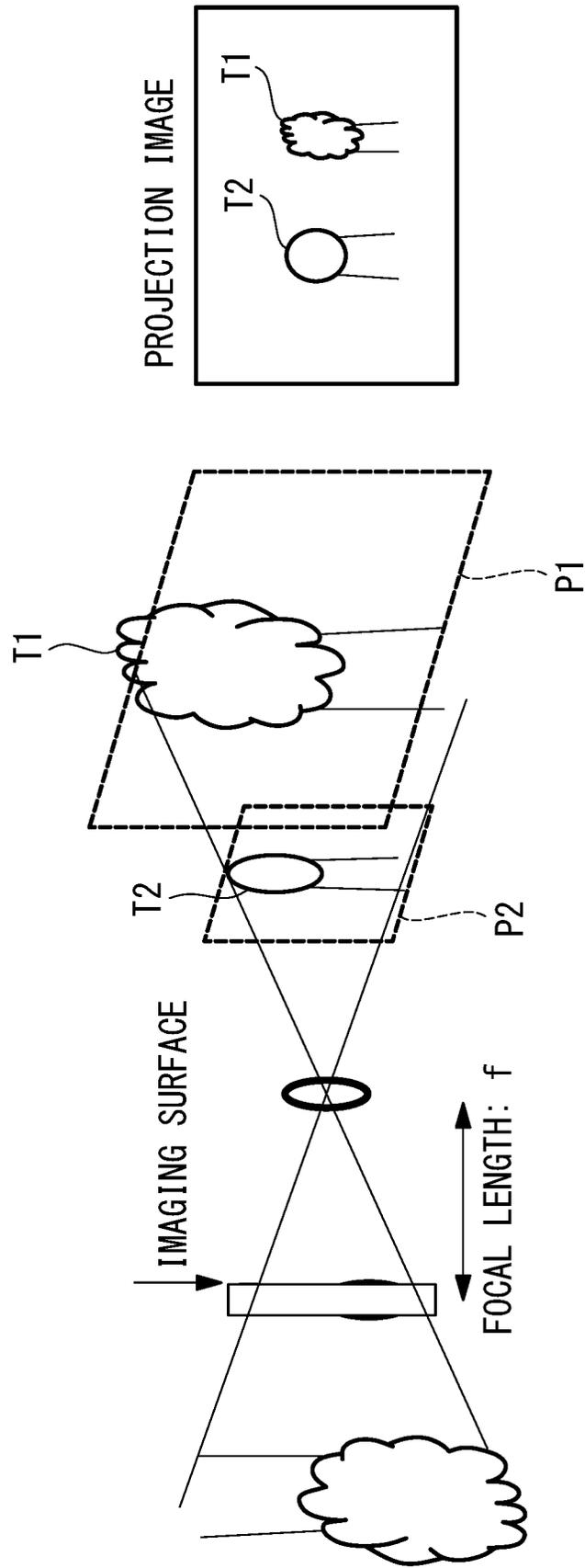


FIG. 8B

BOTH FAR SIDE AND NEAR SIDE ARE SUBJECTED TO RECTILINEAR MOTION BY SAME DISTANCE IN VERTICAL DIRECTION

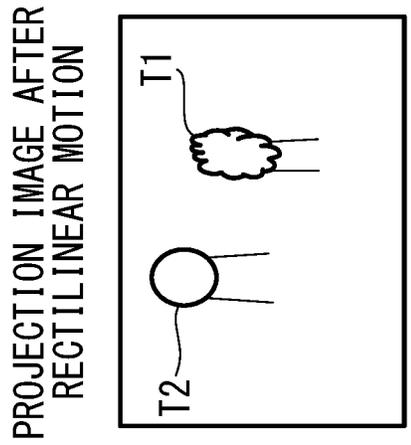
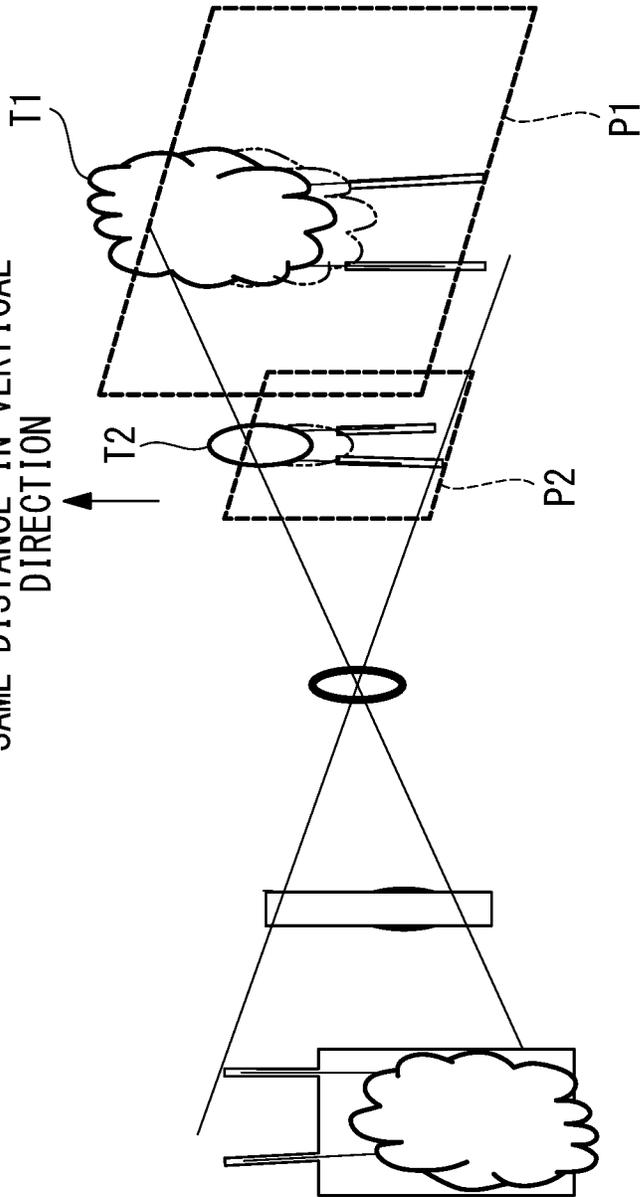


FIG. 9

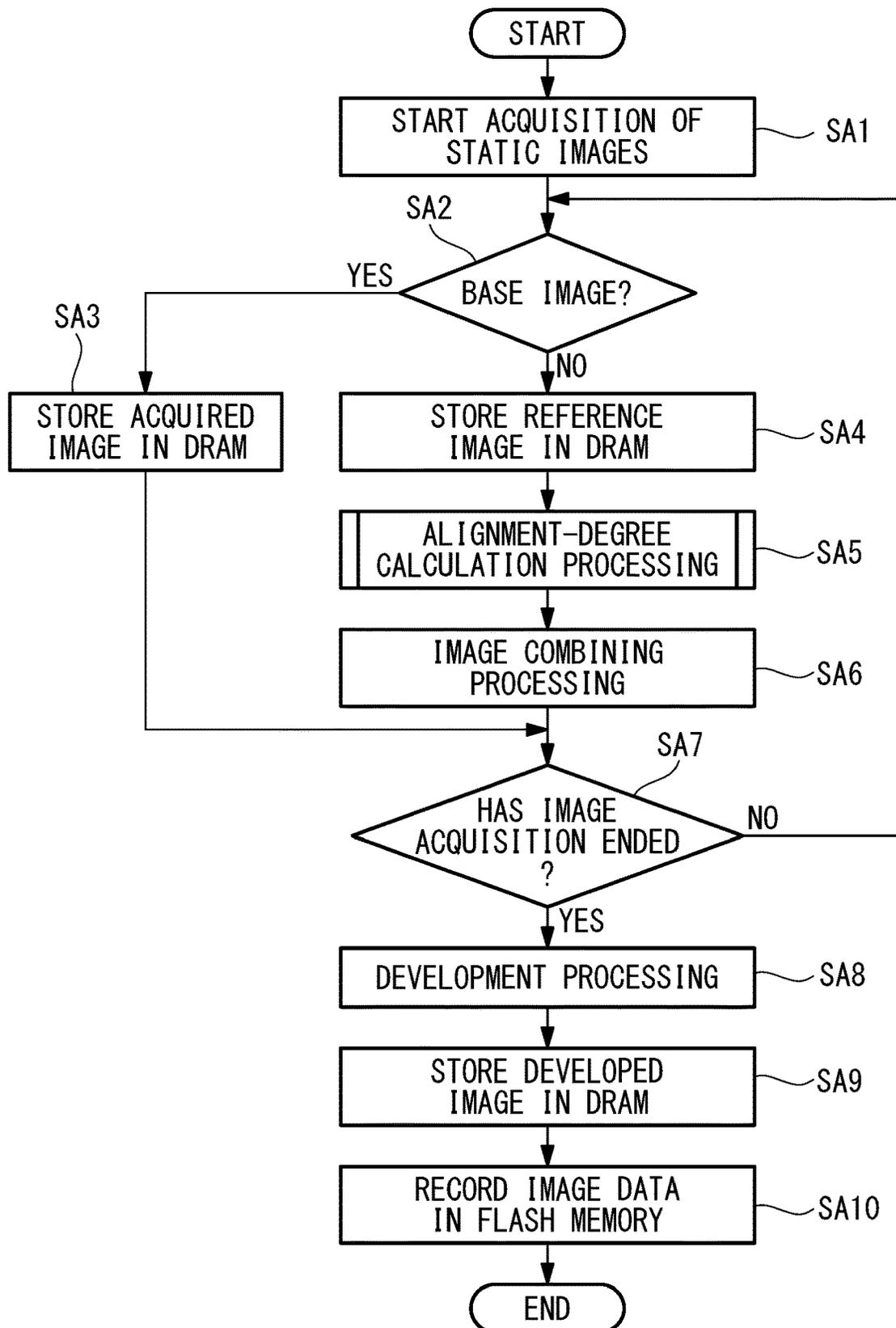
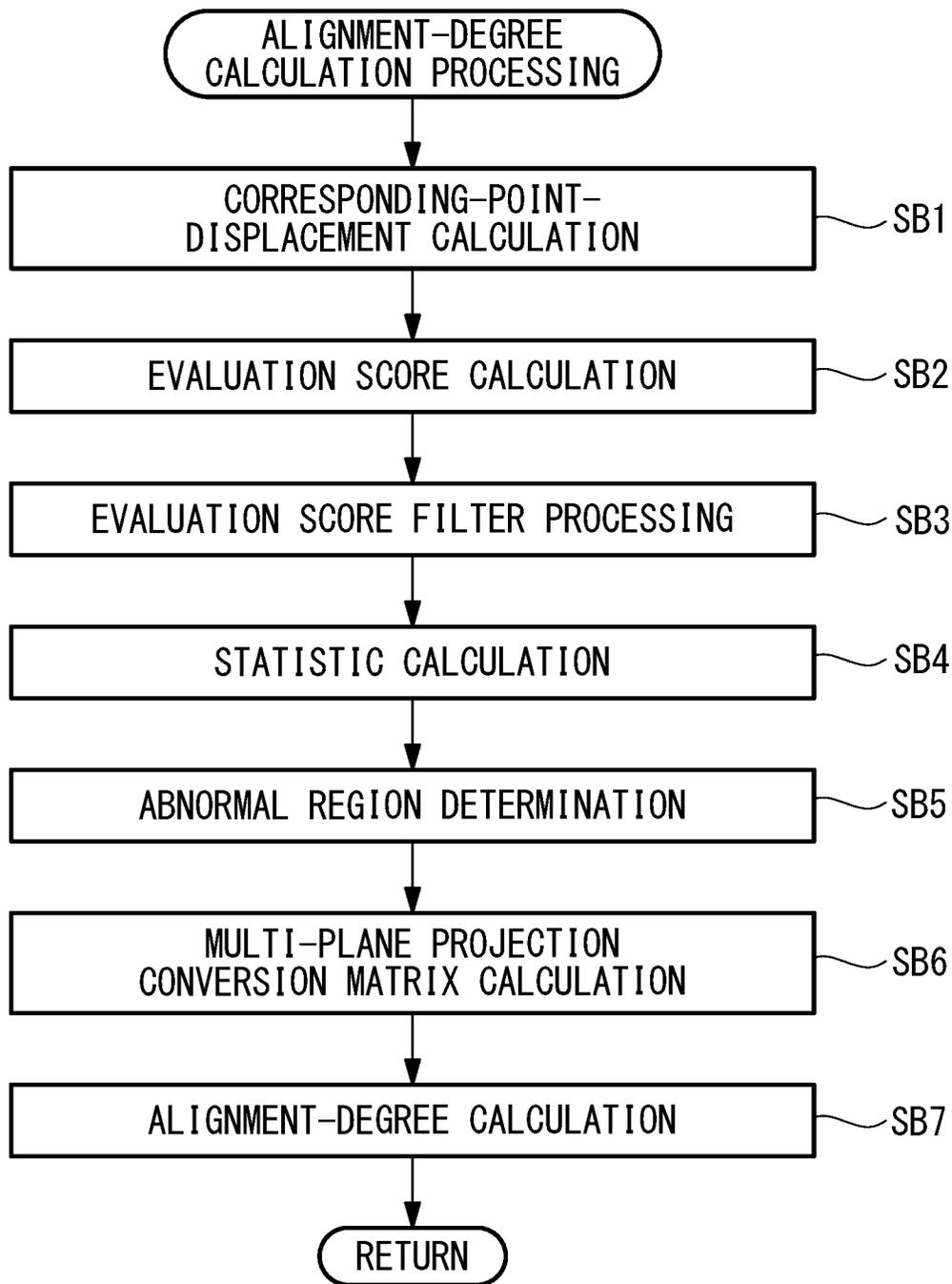


FIG. 10



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# IMAGE PROCESSING DEVICE, IMAGE PROCESSING METHOD, AND IMAGE PROCESSING PROGRAM

## CROSS-REFERENCE TO RELATED APPLICATIONS

This is a continuation of International Application PCT/JP2018/018928 which is hereby incorporated by reference herein in its entirety.

This application claims the benefit of International Application PCT/JP2017/019930, the content of which is incorporated herein by reference.

## TECHNICAL FIELD

The present invention relates to an image processing device, an image processing method, and an image processing program for generating a combined image by combining a plurality of time-sequentially acquired images.

## BACKGROUND ART

In one of the conventional techniques for aligning a plurality of images, the degree of misalignment of each pixel position has been modelled with a projection conversion matrix (for example, refer to PTL 1). This is a method for obtaining the degree of misalignment of each pixel position by acquiring, via the optical flow, feature point matching, or the like, the degrees of misalignment of characteristic regions in a base image and a reference image other than the base image that have been arbitrarily set from among a plurality of images and then by estimating a geometric change of the entire image from information about the degrees of misalignment.

When the degree of misalignment of each pixel position in an image is to be obtained by using a projection conversion matrix, it is possible to accurately calculate in which direction and how much the entire image shifts, as long as the image does not contain objects with depths. However, if the image contains objects with depths, such as an image in which a plurality of planes coexist, the degrees of misalignment differ among regions in different planes, making it necessary to take into account the degree of misalignment for each of the regions. If an appropriate degree of misalignment is not applied to each of the regions, alignment is not correctly performed, leading to an artifact (data error) occurring in a combined image.

PTL 1 discloses an image processing device for generating a combined image by solving such a problem. In order to suppress an artifact, the image processing device described in PTL 1 first obtains a plurality of projection conversion matrices representing the degrees of misalignment. Each of the projection conversion matrices indicates a projection conversion matrix that is optimal for one of the planes in subjects in which a plurality of planes coexist. By switching the projection conversion matrices from one to another, a plurality of images to which the degrees of misalignment have been applied (hereinafter, referred to as position-alignment images) are generated temporarily, and the difference values between these position-alignment images and the base image are obtained. An object region with depth can be appropriately detected by determining that a region having a large difference value is a region on an irrelevant plane having a different degree of misalignment.

In PTL 1, when a projection conversion matrix is to be obtained, first an initial set is produced from three or more

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randomly selected feature points. The size of the set is increased by generating a projection conversion matrix from the feature points contained in the initial set, searching for a feature point that matches conversion performed with that projection conversion matrix, and adding an applicable feature point to the set. When there are no more feature points to be added, this set is established as one set composed of feature points on the same plane. At the same time, the projection conversion matrix used to search for applicable feature points is set as a matrix representing a geometric change of that plane. If no feature points are added to the initial set, it is determined that the initial set is an improper set spanning a plurality of planes, and the initial set is re-produced. Once one set has been established, another initial set is produced by using other feature points not belonging to that established set, a search is made for feature points, and the feature points are added again. A set for each plane can be produced by repeating the above-described processing.

## CITATION LIST

### Patent Literature

{PTL 1}  
Publication of Japanese Patent No. 5499261

## SUMMARY OF INVENTION

One aspect of the present invention is an image processing device for generating a combined image by combining one base image and at least one reference image other than the base image that have been acquired time-sequentially, including: circuitry configured to: calculate a degree of alignment of each pixel of the reference image with respect to each pixel of the base image by using at least one projection conversion matrix; and generate the combined image by converting the reference image on the basis of the calculated degree of alignment and by combining the converted reference image with the base image, wherein in the calculating of the degree of alignment, the circuitry is configured to: calculate a displacement of each of a plurality of corresponding feature regions between the reference image and the base image; classify, as at least one set, other feature regions excluding, from the plurality of feature regions, an abnormal feature region having the displacement that shows a different tendency from the displacement of the other feature regions; and calculate the at least one projection conversion matrix by using the displacement of the other feature regions and the result of the classifying the other feature regions, wherein in the classifying the other feature regions, the circuitry is configured to: calculate an evaluation score of each of the plurality of feature regions by using the calculated displacement; and determine the abnormal region on the basis of the calculated evaluation score, and wherein in the calculating the evaluation score, the circuitry is configured to: calculate, as the evaluation score, the difference value between the displacements of two feature regions adjacent to each other in at least one of the up/down direction, the left/right direction, and the oblique 45° direction; and apply filter processing to the calculated evaluation score.

Another aspect of the present invention is an image processing method for generating a combined image by combining one base image and at least one reference image other than the base image that have been acquired time-sequentially, including: calculating a degree of alignment of

each pixel of the reference image with respect to each pixel of the base image by using at least one projection conversion matrix; and generating the combined image by converting the reference image on the basis of the calculated degrees of alignment and by combining the converted reference image with the base image, wherein in the calculating of the degree of alignment: calculating a displacement of each of a plurality of corresponding feature regions between the reference image and the base image; classifying, as at least one set, other feature regions excluding, from the plurality of feature regions, an abnormal feature region having the displacement that shows a different tendency from the displacement of the other feature regions; and calculating the at least one projection conversion matrix by using the displacement of the other feature regions and the result of the classifying the other feature regions, wherein in the classifying the other feature regions: calculating an evaluation score of each of the plurality of feature regions by using the calculated displacement; and determining the abnormal region on the basis of the calculated evaluation score, and wherein in the calculating the evaluation score: calculating, as the evaluation score, the difference value between the displacements of two feature regions adjacent to each other in at least one of the up/down direction, the left/right direction, and the oblique 45° direction; and applying filter processing to the calculated evaluation score.

Another aspect of the present invention is a non-transitory computer-readable medium having an image processing program for causing a computer to execute processing for generating a combined image by combining one base image and at least one reference image other than the base image that have been acquired time-sequentially is stored thereon, the program causing the computer to execute functions of: calculating a degree of alignment of each pixel of the reference image with respect to each pixel of the base image by using at least one projection conversion matrix; and generating the combined image by converting the reference image on the basis of the calculated degrees of alignment and by combining the converted reference image with the base image, wherein in the calculating of the degree of alignment: calculating a displacement of each of a plurality of corresponding feature regions between the reference image and the base image; classifying, as at least one set, other feature regions excluding, from the plurality of feature regions, an abnormal feature region having the displacement that shows a different tendency from the displacement of the other feature regions; and calculating the at least one projection conversion matrix by using the displacement of the other feature regions and the result of the classifying the other feature regions, wherein in the classifying the other feature regions: calculating an evaluation score of each of the plurality of feature regions by using the calculated displacement; and determining the abnormal region on the basis of the calculated evaluation score, and wherein in the calculating the evaluation score: calculating, as the evaluation score, the difference value between the displacements of two feature regions adjacent to each other in at least one of the up/down direction, the left/right direction, and the oblique 45° direction; and applying filter processing to the calculated evaluation score.

#### BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a block diagram schematically showing an example of the structure of an image processing device and an image acquisition system according to one embodiment of the present invention.

FIG. 2 is a block diagram schematically showing an example of the structure of an image processing unit in FIG. 1.

FIG. 3 is a block diagram schematically showing an example of the structure of an alignment-degree calculation unit in FIG. 2.

FIG. 4A is a diagram showing one example of an acquired image of one subject, illustrating displacements of feature points in a case where the image contains only one plane.

FIG. 4B is a diagram showing one example of the image in FIG. 4A in a case where a camera is subjected to motion.

FIG. 5A is a diagram showing one example of an acquired image of two subjects having different depths and a moving object, illustrating displacements of feature points in a case where the image contains two planes and a disturbance.

FIG. 5B is a diagram showing one example of the image in FIG. 5A in a case where a camera is subjected to motion.

FIG. 6A is a diagram for illustrating a statistic in the vertical direction calculated from the image in FIG. 4B.

FIG. 6B is a diagram for illustrating processing for determining an abnormal region on the basis of statistics in the vertical direction and horizontal direction from the image in FIG. 4B.

FIG. 7A is a diagram for illustrating a statistic in the vertical direction calculated from the image in FIG. 5B.

FIG. 7B is a diagram for illustrating processing for determining an abnormal region on the basis of statistics in the vertical direction and horizontal direction from the image in FIG. 5B.

FIG. 8A is a diagram showing one example projection of an acquired image of two subjects having different depths.

FIG. 8B is a diagram showing one example projection of an image of the subjects in FIG. 8A in a case where a camera is subjected to rectilinear motion.

FIG. 9 is a flowchart for illustrating an image processing method according to one embodiment of the present invention.

FIG. 10 is a flowchart for illustrating alignment-degree calculation processing in FIG. 9.

#### DESCRIPTION OF EMBODIMENTS

An image processing device, an image acquisition system, an image processing method, and an image processing program according to one embodiment of the present invention will now be described with reference to the drawings.

An image acquisition system 100 according to this embodiment is, for example, a digital camera. As shown in FIG. 1, this image acquisition system 100 includes: an image acquisition unit 1 for acquiring a plurality of images of a subject (not shown in the figure); an analog amplifier (A-AMP) 3; an analog-to-digital converter (ADC) 5; a dynamic random access memory (DRAM) 7; an image processing unit (image processing device) 9; a video encoder 11; a display section 13; a central processing unit (CPU) 15; an operating section 17; and a FLASH memory 19. In FIG. 1, the solid-line arrows indicate data flows, and the dashed-line arrows indicate control signal flows.

The image acquisition unit 1 includes: an image acquisition lens 21 for collecting light from the subject; an aperture stop 23 for restricting the amount of a light beam collected by the image acquisition lens 21; a mechanical shutter 25 capable of shutting off the light passing through the aperture stop 23; and an image acquisition element 27 for acquiring an image of the light that has passed through the mechanical shutter 25.

The image acquisition lens **21** is an optical system composed of one or more lenses for forming an image of the subject on the image acquisition element **27**. The image acquisition lens **21** may be a fixed focal length lens or a zoom lens.

The aperture stop **23** is disposed on the optical axis of the image acquisition lens **21** and is configured so that the opening size thereof is variable.

The mechanical shutter **25** is disposed behind the aperture stop **23** and is configured to be openable/closable. The incident time for which a subject light beam from the subject is incident upon the image acquisition element **27** can be adjusted by adjusting the open time of the mechanical shutter **25**. In other words, the mechanical shutter **25** is configured to be capable of adjusting the exposure time of the image acquisition element **27**. As the mechanical shutter **25**, a well-known focal-plane shutter, a well-known lens shutter, or the like can be employed.

The image acquisition element **27** is disposed at a position that is behind the mechanical shutter **25**, that is on the optical axis of the image acquisition lens **21**, and at which an image of the subject light beam is formed by the image acquisition lens **21**. This image acquisition element **27** has a plurality of photodiodes (not shown in the figure) that are arrayed two-dimensionally and that constitute respective pixels.

The photodiodes constituting the image acquisition element **27** generate electric charge according to the amount of received light. The electric charge generated in the photodiodes is stored in a capacitor connected to each of the photodiodes. The electric charge stored in the capacitor is read out as an image signal according to a control signal from the CPU **15**.

Color filters (not shown in the figure) in, for example, a Bayer array are disposed on the front faces of the photodiodes constituting the pixels. The Bayer array has, in the horizontal direction, lines in which R pixels and G (Gr) pixels are alternately arranged and lines in which G (Gb) pixels and B pixels are alternately arranged.

The A-AMP **3** adjusts the analog gain of an image signal sent from the image acquisition element **27**.

The ADC **5** converts the image signal that has been subjected to analog gain adjustment by the A-AMP **3** into an image signal (pixel data) in a digital format. Hereinafter, in the present description, a group of multiple pieces of pixel data are denoted as imaging data. In addition, a value related to each pixel indicated by pixel data is denoted as a pixel value. Imaging data generated by the ADC **5** is written into the DRAM **7**.

The DRAM **7** is an electrically rewritable memory and can temporarily store various types of data, such as imaging data (pixel data), recording image data, display image data, and processing data in the CPU **15**. For the purpose of temporary storage, a synchronous dynamic random access memory (SDRAM), instead of the DRAM **7**, may be used.

The image processing unit **9** is configured by, for example, an application specific integrated circuit (ASIC). The image processing unit **9** reads out image data from the DRAM **7**, performs image processing, and writes the image data back to the DRAM **7** as display image data and recording image data. For example, when a static image is to be recorded, the image processing unit **9** generates static image data by performing image processing for recording a static image and, when a dynamic image is to be recorded, the image processing unit **9** generates dynamic image data by performing image processing for recording a dynamic image. Furthermore, at the time of live view display, the

image processing unit **9** generates display image data by applying image processing for display to the image data read out from the DRAM **7**.

The image processing in the image processing unit **9** will be described later in detail.

The video encoder **11** reads out display image data that has been generated by the image processing unit **9** and that has been temporarily stored in the DRAM **7** and outputs the read-out display image data to the display section **13**.

The display section **13** is, for example, a liquid crystal display (LCD) or an organic EL display and is disposed on, for example, the back face of the digital camera. The display section **13** displays an image according to the display image data sent from the video encoder **11**. The display section **13** can also be used for live view display, display of recorded images, etc.

The CPU **15** issues control signals to control the image acquisition element **27**, control the opening size of the aperture stop **23**, control the opening and closing of the mechanical shutter **25**, drive the image processing unit **9**, drive the video encoder **11**, and control the entire image acquisition system **100**. In addition, the CPU **15** determines whether an image acquired by the image acquisition element **27** is a base image or a reference image.

The operating section **17** includes various types of operating buttons, such as a power button, a release button, a playback button, and a menu button, and various types of operating members such as a touch panel. A user's instruction that has been input by the operating section **17** is recognized through processing performed by the CPU **15**.

The FLASH memory **19** is incorporated in the image acquisition system **100** serving as the digital camera or is configured so as to be capable of being inserted into the image acquisition system **100** and can record recording image data as an image file in a predetermined format.

In FIG. 1, reference sign **71** denotes a bus. The bus **71** is connected to the ADC **5**, the DRAM **7**, the CPU **15**, the image processing unit **9**, the FLASH memory **19**, and the video encoder **11**. Various types of data generated in each of these sections **5**, **7**, **9**, **11**, **15**, and **19** are transferred via the bus **71**.

Next, the image processing unit **9** will be described.

As shown in FIG. 2, the image processing unit **9** includes: an alignment-degree calculation unit **29**; an image combining unit **31**; a white balance (WB) correction processing unit **33**; a synchronization processing unit **35**; a brightness characteristics conversion unit **37**; an edge enhancement processing unit **39**; a noise reduction (NR) processing unit **41**; and a color reproduction processing unit **43**.

The various types of component units constituting the image processing unit **9** are not limited to the above-described component units but include other component units. Other component units in the image processing unit **9** include, for example, a compression/decompression processing unit etc. However, component units other than the above-described component units are not related directly to the present invention, and diagrammatic representations and explanations thereof will be omitted.

The alignment-degree calculation unit **29** reads, from the DRAM **7**, the base image, serving as a base, and at least one reference image other than the base image among a plurality of images acquired by the image acquisition unit **1** and calculates the degree of misalignment (displacement) of each pixel in the reference image with respect to each pixel in the read-out base image. More specifically, as shown in FIG. 3, the alignment-degree calculation unit **29** includes: a corresponding-point-displacement calculation unit (corre-

sponding-region-displacement calculation unit) **51**; a clustering processing unit **53**; and a multi-plane projection conversion matrix calculation unit (projection conversion matrix calculation unit) **55**.

The corresponding-point-displacement calculation unit **51** obtains, from the base image and the reference image that have been arbitrarily set from among the plurality of images, the degrees of misalignment (displacement) of feature points (feature regions), serving as characteristic regions, in the images by means of the optical flow, feature point matching, or the like. Therefore, the feature points have coarse resolution, compared with the base image and the reference images.

The clustering processing unit **53** analyzes the tendency of the degrees of misalignment of the feature points output from the corresponding-point-displacement calculation unit **51**, and detects, as an abnormal region, a feature point having a degree of misalignment that differs from the tendency of the degrees of misalignment of the other feature points. Before processing performed by the clustering processing unit **53** is described, the purpose of processing performed by the clustering processing unit **53** will be described with reference to FIGS. **4A** to **5B**.

Processing performed by the clustering processing unit **53** is intended particularly to remove a disturbance, which would be erroneously recognized as camera motion. FIG. **4A** shows an image of a subject **S1** having only one plane, and FIG. **4B** shows an image in which the subject **S1** in FIG. **4A** is deformed as a result of the camera being subjected to motion with six degrees of freedom. In the example in FIG. **4B**, a feature point **p1** in the upper part of the image shows a low degree of misalignment, feature points **p2** and **p3** in the middle part of the image show a slightly higher degree of misalignment than in the upper part of the image, and a feature point **p4** in the lower part of the image shows an even higher degree of misalignment than in the upper part of the image.

On the other hand, FIG. **5A** shows an image including a subject **S2** at a long distance, a subject **S3** at a middle distance, and a moving object **S4** that moves relative to the subjects **S2** and **S3**, which are stationary. This image includes two planes on which the subjects **S2** and **S3** are present and one disturbance formed of the moving object **S4**. FIG. **5B** shows an image in which the subjects **S2** and **S3** in FIG. **5A** have shifted to the right of the image and the moving object **S4** has greatly moved to the right of the image as a result of the camera being subjected to only rectilinear motion towards the left of the image.

In the example in FIG. **5B**, a feature point **q1** corresponding to the subject **S2** at a long distance in the upper part of the image shows a low degree of misalignment, feature points **q2** and **q3** corresponding to the subject **S3** at a middle distance in the middle part of the image show a slightly higher degree of misalignment than in the upper part of the image. In the lower part of the image in which the subject **S3** at a middle distance and the moving object **S4** are present, feature points **q4** and **q5** in the region of the moving object **S4** show a higher degree of misalignment than in the upper part and in the middle part of the image.

Here, in the subject **S1** in FIG. **4B**, if a camera motion can be correctly estimated by obtaining a projection conversion matrix from an initial set composed of the feature points **p1**, **p2**, and **p3** in the upper part and the middle part of the image, one plane is established because the motion of the feature point **p4** in the lower part of the image coincides with the degree of misalignment obtained from the projection conversion matrix.

In the subjects **S2** and **S3** in FIG. **5B**, if camera motion can be correctly estimated by obtaining, in the same manner, a projection conversion matrix from an initial set composed of the feature points **q1**, **q2**, and **q3** in the upper part and the middle part of the image, the motions of the feature points **q4** and **q5** in the lower part do not coincide with the degree of misalignment obtained with the projection conversion matrix, thus failing to establish a plane unless the moving object **S4** is present. Note that if the motions of the feature points **q4** and **q5** in the moving object **S4** coincide with the degree of misalignment obtained with the projection conversion matrix, one plane spanning the two planes on which the subjects **S2** and **S3** are present is erroneously established.

In order to avoid such a problem, the clustering processing unit **53** performs processing for eliminating the influence of a disturbance.

The clustering processing unit **53** includes: an evaluation score calculation unit **57** for calculating, for each of the feature points, an evaluation score serving as an index for determining a disturbance; and an abnormal region determination unit **59** for determining whether or not each of the feature points is an abnormal region due to a disturbance on the basis of the evaluation score calculated by the evaluation score calculation unit **57**.

The evaluation score calculation unit **57** includes: an acceleration evaluation score calculation unit **61**; and an evaluation score filter processing unit **63**.

The acceleration evaluation score calculation unit **61** obtains, as an evaluation score, the difference value of the degree of misalignment between two adjacent feature points in each of the horizontal direction (X direction) and the vertical direction (Y direction) of an image. The difference values are calculated from, for example, the following expressions. By doing so, the X-direction acceleration and the Y-direction acceleration at each position (n, m) are calculated in the form of difference values. n (n=1, 2, . . . , h) indicates a horizontal position in the image, and m (m=1, 2, . . . , v) indicates a vertical position in the image.

$$\text{dif\_Hor\_X}(n,m)=\Delta X(n+1,m)-\Delta X(n,m)$$

$$\text{dif\_Hor\_Y}(n,m)=\Delta Y(n+1,m)-\Delta Y(n,m)$$

$$\text{dif\_Ver\_X}(n,m)=\Delta X(n,m+1)-\Delta X(n,m)$$

$$\text{dif\_Ver\_Y}(n,m)=\Delta Y(n,m+1)-\Delta Y(n,m)$$

Here,

$\Delta X(n, m)$ : degree of misalignment in the X direction at (n, m),

$\Delta Y(n, m)$ : degree of misalignment in the Y direction at (n, m),

$\Delta X(n+1, m)$ : degree of misalignment in the X direction at (n+1, m),

$\Delta Y(n+1, m)$ : degree of misalignment in the Y direction at (n+1, m),

$\text{dif\_Hor\_X}(n, m)$ : horizontal acceleration in the X direction at (n, m),

$\text{dif\_Hor\_Y}(n, m)$ : horizontal acceleration in the Y direction at (n, m),

$\text{dif\_Ver\_X}(n, m)$ : vertical acceleration in the X direction at (n, m), and

$\text{dif\_Ver\_Y}(n, m)$ : vertical acceleration in the Y direction at (n, m).

This embodiment has been described by way of an example where the acceleration evaluation score calculation unit **61** obtains, as an evaluation score, the difference value of the degree of misalignment between two adjacent feature

points in each of the horizontal direction (X direction) and the vertical direction (Y direction) of an image. Instead of this, the difference value of the degree of misalignment between two adjacent feature points in an oblique 45° direction of the image may be used as an evaluation score.

The evaluation score filter processing unit 63 arrays a group of the accelerations calculated by the acceleration evaluation score calculation unit 61 in a two-dimensional space defined by the horizontal position n and the vertical position m and applies a two-dimensional spatial filter to the group of accelerations in the two-dimensional space. The accelerations calculated by the acceleration evaluation score calculation unit 61 ideally change linearly in regions other than a disturbance region. The fact is, however, that the accelerations also suffer relatively small peaks due to the influence of noise also in regions other than a disturbance region. The evaluation score filter processing unit 63 suppresses such a fluctuation in acceleration brought about by an error in the degree of misalignment and performs processing for further enhancing a sharp change in acceleration caused by a disturbance.

More specifically, the evaluation score filter processing unit 63 applies an edge enhancement filter and a noise reduction filter, such as a low pass filter, to the group of accelerations. Alternatively, the evaluation score filter processing unit 63 may apply, to the group of accelerations, an edge-retaining smoothing filter, such as a bilateral filter, for suppressing noise by performing smoothing while retaining edges. By doing so, a change in acceleration can be determined more accurately. It should be noted, however, that either of an edge enhancement filter and a noise reduction filter may be used independently in consideration of the number of arithmetic operations etc.

The abnormal region determination unit 59 includes a statistic calculation unit 65 and a region determination unit 67.

The statistic calculation unit 65 performs statistical processing of the group of accelerations that have been subjected to filtering by the evaluation score filter processing unit 63, thereby generating a statistic that serves as an index for determining whether or not each position in the horizontal direction and each position in the vertical direction correspond to a boundary of an abnormal region.

More specifically, the statistic calculation unit 65 calculates statistics Sta\_H(n) and Sta\_V(m) from the following expressions by using the accelerations dif\_Hor\_X(n, m), dif\_Hor\_Y(n, m), dif\_Ver\_X(n, m), and dif\_Ver\_Y(n, m) that have been subjected to filtering.

$$\text{Sta\_H}(n)=\max(\text{dif\_Hor\_X}(n,0)+\text{dif\_Hor\_Y}(n,0),\text{dif\_Hor\_X}(n,1)+\text{dif\_Hor\_Y}(n,1),\dots,\text{dif\_Hor\_X}(n,k)+\text{dif\_Hor\_Y}(n,v))$$

$$\text{Sta\_V}(m)=\max(\text{dif\_Ver\_X}(0,m)+\text{dif\_Ver\_Y}(0,m),\text{dif\_Ver\_X}(1,m)+\text{dif\_Ver\_Y}(1,m),\dots,\text{dif\_Ver\_X}(h,m)+\text{dif\_Ver\_Y}(h,m))$$

Here,

Sta\_H(n): statistic at the horizontal position n,

Sta\_V(m): statistic at the vertical position m,

h: maximum number of horizontal positions, and

v: maximum number of vertical positions.

In the above-described example, the statistic Sta\_H(n) is the maximum value of the sums of the X-direction accelerations and the Y-direction accelerations at the same horizontal position, and the statistic Sta\_V(m) is the maximum value of the sums of the X-direction accelerations and the Y-direction accelerations at the same vertical position. The type of statistic calculated by the statistic calculation unit 65

is not limited to that described above but may be other types of statistics. For example, the type of statistic may be a mean value, an integrated value, a median value, or a minimum value. Alternatively, a combination of a plurality of types of statistics may be used.

The region determination unit 67 determines a boundary of an abnormal region on the basis of the statistics Sta\_H(n) and Sta\_V(m) calculated by the statistic calculation unit 65.

FIG. 6A shows a statistic in the vertical direction in the subject S1 in FIG. 4B. The degrees of misalignment of feature positions (refer to the circle marks) increase from the upper part to the lower part of the image at a substantially constant acceleration, and hence, the accelerations indicate a substantially constant value. When there are no sharp changes in acceleration as described above, the region determination unit 67 determines that there are no abnormal regions and classifies all feature points into the same set.

On the other hand, FIG. 7A shows a statistic in the vertical direction in the subjects S2, S3, and S4 in FIG. 5B. As shown in FIG. 7A, the acceleration is zero in the same plane, and the acceleration indicates a value other than zero at a boundary between two planes and at a position where the moving object S4 is present. In particular, the change in acceleration can be sharp at a position of the moving object S4, serving as a disturbance. In the case where a sharp change in acceleration occurs in this manner, the region determination unit 67 determines that there is an abnormal region. Then, the region determination unit 67 classifies the feature points corresponding to the abnormal region into one set and classifies the feature points corresponding to a non-abnormal region, defined as a region other than the abnormal region, into another set.

Information about the results of feature point analysis performed by the region determination unit 67 is input from the region determination unit 67 to the multi-plane projection conversion matrix calculation unit 55.

FIGS. 6B and 7B are drawings for illustrating a method for determining an abnormal region.

In order to calculate a statistic at the vertical position m, the vertical-direction accelerations dif\_Ver\_X(n, m) and dif\_Ver\_Y(n, m) are first calculated for all horizontal positions n=1, 2, . . . , h. Then, of the calculated accelerations, the maximum acceleration is determined to be the statistic at the vertical position m. By performing this processing for each of the vertical positions m=1, 2, . . . , v, a statistic at each of the vertical positions can be calculated.

As a result of such calculations, because there are no sharp vertical-direction accelerations at any horizontal position in the example in FIG. 6B, no abnormal regions are present.

On the other hand, in the example in FIG. 7B, the largest acceleration is detected in a region in the lower part of the image, i.e., the region in which the moving object S4 is present. In this case, the vertical position at which the largest acceleration is detected is determined to be a boundary at which a region is switched to another, and the region from the boundary to the maximum vertical position v is determined to be an abnormal region.

By performing similar processing also in the horizontal direction, the horizontal and vertical ranges of the abnormal region are determined.

Note that although only the largest statistic is determined to be an abnormal region in the above description, the method for determining an abnormal region is not limited to this. For example, the region determination unit 67 may determine that a horizontal position and a vertical position having a statistic that is equal to or larger than a predeter-

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mined threshold value is a boundary between an abnormal region and a non-abnormal region. Alternatively, the region determination unit 67 may calculate the difference between the statistics at two horizontal positions adjacent to each other, as well as the difference between the statistics at two vertical positions adjacent to each other, and may determine that each of the region between two horizontal positions and the region between two vertical positions is a boundary between an abnormal region and a non-abnormal region if the calculated difference between the statistics for those regions is equal to or larger than a predetermined threshold value. In this manner, the boundary between an abnormal region and a non-abnormal region can also be accurately determined on the basis of the magnitude of the statistic and the difference between the statistics at two adjacent positions. In addition, when a plurality of statistics equal to or larger than a predetermined threshold value are detected, a plurality of abnormal regions may be set.

The multi-plane projection conversion matrix calculation unit 55 calculates a projection conversion matrix for each of the planes on which the degrees of misalignment in the reference image are different from one another. More specifically, the multi-plane projection conversion matrix calculation unit 55 generates at least one initial set by classifying, into the same set, feature points assumed to belong to the same plane. At this time, on the basis of the result of classification of feature points input from the clustering processing unit 53, the multi-plane projection conversion matrix calculation unit 55 produces initial sets composed of the other feature points that have remained as a result of the feature points in the abnormal region being excluded. Next, the multi-plane projection conversion matrix calculation unit 55 obtains a projection conversion matrix by using information about the feature points in each of the initial sets. Therefore, if a plurality of planes having different degrees of misalignment are present in the reference image, a plurality of projection conversion matrices in which the respective degrees of misalignment are modelled are calculated.

Here, as shown in FIG. 8A, subjects having two respective planes P1 and P2 located at depths different from each other are assumed. A far-side subject (tree) T1 is larger than a near-side subject (human) T2 in the real world. However, because the far-side subject T1 has a longer object distance than the near-side subject T2, the far-side subject T1 becomes smaller in an acquired projection image. For this reason, even though the far-side subject T1 is much larger in size than the near-side subject T2 in the real world, the far-side subject T1 and the near-side subject T2 can appear the same size in the projection image.

In this situation, if the camera is subjected to rectilinear motion, for example, as shown in FIG. 8B, the near-side subject T2 with a short object distance moves by a large distance in the projection image while the far-side subject T1 with a long object distance moves by a short distance. For this reason, the degree of misalignment differs according to the image region of each of the subjects T1 and T2 with different object distances. Because there are a plurality of degrees of misalignment in the image in this manner, a plurality of projection conversion matrices are required in order to correctly align the subjects T1 and T2.

The multi-plane projection conversion matrix calculation unit 55 calculates a plurality of projection conversion matrices for respective planes and then calculates the degree of alignment for each pixel position. For example, the multi-plane projection conversion matrix calculation unit 55 calculate reference-image coordinates on the base image.

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It is assumed that: a coordinate position on the reference image is denoted as x, y; a coordinate position to be calculated on the base image is denoted as x', y'; and the result of selecting the plane of the pixel position x, y is denoted as P(x, y).

In the case where P(x, y) is a plane A, the coordinate position x', y' on the base image is obtained from expression (1) below.

$$\begin{pmatrix} x' \\ y' \\ 1 \end{pmatrix} = \begin{pmatrix} H1 & H2 & H3 \\ H4 & H5 & H8 \\ H7 & H6 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ 1 \end{pmatrix} \quad (1)$$

HERE,  $\begin{pmatrix} H1 & H2 & H3 \\ H4 & H5 & H8 \\ H7 & H6 & 1 \end{pmatrix}$  PROJECTION CONVERSION MATRIX OF PLANE A

In the case where P(x, y) is a plane B, the coordinate position x', y' on the base image is obtained from expression (2) below.

$$\begin{pmatrix} x' \\ y' \\ 1 \end{pmatrix} = \begin{pmatrix} G1 & G2 & G3 \\ G4 & G5 & G8 \\ G7 & G6 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ 1 \end{pmatrix} \quad (2)$$

HERE,  $\begin{pmatrix} G1 & G2 & G3 \\ G4 & G5 & G8 \\ G7 & G6 & 1 \end{pmatrix}$  PROJECTION CONVERSION MATRIX OF PLANE B

When a coordinate position on the reference image is to be aligned with a coordinate position on the base image, the multi-plane projection conversion matrix calculation unit 55 calculates the degrees of alignment dif\_x and dif\_y from expressions (3) and (4) below.

$$\text{dif}_x = x - x' \quad (3)$$

$$\text{dif}_y = y - y' \quad (4)$$

The plane projection conversion matrix to be applied to each pixel can be determined by the method described in, for example, PTL 1 (Publication of Japanese Patent No. 5499261). More specifically, a plurality of position-alignment images that have been geometrically converted with respective plane projection conversion matrices are generated, the difference value between the base image and each of the position-alignment images is obtained for each pixel, and the projection conversion matrix used to generate the position-alignment image with the smallest difference is finally applied. It should be noted, however, that this method is merely one example, and the projection conversion matrix to be applied to each pixel may be determined according to another method.

Referring back to FIG. 2, the image combining unit 31 applies geometric conversion to, for example, a reference image on the basis of the degrees of alignment dif\_x and dif\_y calculated by the alignment-degree calculation unit 29 and combines the converted reference image with the base image, thus generating a combined image.

Combining processing may be performed by, for example, a method for simply arithmetically averaging the pixel values at the same coordinate positions on a position-alignment image and the base image, and thus the method is not limited. Combining processing may also be performed

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for various purposes including noise reduction, HDR (High Dynamic Range), super-resolution, etc., and thus the purposes thereof are not limited.

The white balance correction processing unit **33** amplifies, with a predetermined amount of gain, each of the color components of data of the combined image generated by the image combining unit **31**, thereby correcting the color balance of the combined image.

The synchronization processing unit **35** converts, into image data in which one pixel has a plurality of color components, the combined image, which has been generated by using imaging data in which one pixel has one color component corresponding to the Bayer array of the color filter of the image acquisition element **27**.

The brightness characteristics conversion unit **37** converts brightness characteristics of the combined image generated by the synchronization processing unit **35** so as to be suitable for display and recording.

The edge enhancement processing unit **39** multiplies, by an edge enhancement factor, an edge signal extracted by using a band-pass filter etc. from the output data (image data) of the combined image, which has been input from the brightness characteristics conversion unit **37**, and adds the result to the image data of the original combined image, thereby enhancing the edge (outline) component in the image data of the target combined image.

The noise reduction processing unit **41** removes, by using coring processing etc., noise components in the output data (image data) of the combined image that has been input from the edge enhancement processing unit **39**.

The color reproduction processing unit **43** performs various types of processing for achieving appropriate color reproduction of the combined image. Processing performed by the color reproduction processing unit **43** includes, for example, a color matrix arithmetic operation. In the color matrix arithmetic operation, data of the combined image is multiplied by, for example, a color matrix factor according to the white balance mode. In addition to this, the color reproduction processing unit **43** performs, for example, processing for correcting color saturation/hue.

Next, the operation of the image acquisition system **100** and the image processing method including the image processing unit **9** with the above-described configuration will be described.

The flowchart in FIG. **9** shows one example of processing for recording static images performed by the image acquisition system **100** according to this embodiment. Static image recording starts when, for example, the operating section **17**, serving as the release button, is pressed during live view display. Although processing for recording static images will be described here, similar processing is also performed for the operation of dynamic image recording. Note that the processing described with reference to FIG. **9** is controlled by the CPU **15** and is executed by the ASIC of the image processing unit **9**. Programs related to this processing can also be recorded in various types of recording media, such as an optical disk, a magnetic disk, and a semiconductor memory.

First, as shown in the flowchart in FIG. **9**, image acquisition for static image recording is started through the operation of the CPU **15** (step SA1), and it is determined whether or not the current image acquisition is for the base image (step SA2). The determination as to whether or not the current image acquisition is for the base image can be made depending on whether or not the current image acquisition is for, for example, the first static image among the time-sequentially acquired successive static images.

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If the current image acquisition is for the base image, the acquired image is written as the base image into the DRAM **7** via the bus **71** (step SA3), and the flow proceeds to the next image acquisition. The base image written into the DRAM **7** is stored in the DRAM **7** until successive image acquisition ends.

If the current image acquisition is not for the base image, the acquired image is stored as a reference image in the DRAM **7** via the bus **71** (step SA4).

Next, the base image and the reference image stored in the DRAM **7** are read out by the image processing unit **9**, and degrees of alignment dif\_x and dif\_y are calculated by the alignment-degree calculation unit **29** (step SA5). Details of alignment-degree calculation processing in step SA5 will be described later.

Next, the image combining unit **31** applies geometric conversion to the reference image on the basis of the degrees of alignment dif\_x and dif\_y calculated by the alignment-degree calculation unit **29** and combines the converted reference image with the base image, thus generating a combined image (step SA6).

Subsequently, the CPU **15** determines whether or not the successive image acquisition has ended (step SA7). More specifically, the CPU **15** determines whether or not an instruction for ending successive image acquisition has been input. An instruction for ending image acquisition is input, for example, when the release button, serving as the operating section **17**, is pressed again while a still image is being acquired. If no instructions for ending successive image acquisition are input, the flow returns to step SA2 to acquire the next reference image. On the other hand, if an instruction for ending image acquisition has been input, the flow proceeds to step SA8.

Next, the white balance correction processing unit **33**, the synchronization processing unit **35**, the brightness characteristics conversion unit **37**, the edge enhancement processing unit **39**, the noise reduction processing unit **41**, and the color reproduction processing unit **43** in the image processing unit **9** perform development processing of the combined image (step SA8).

The combined image that has been subjected to development processing in the image processing unit **9** is written into the DRAM **7** via the bus **71** (step SA9).

The recording combined image written into the DRAM **7** is recorded by the CPU **15** in the FLASH memory **19** (step SA10). Thereafter, processing ends.

Next, details of the alignment-degree calculation processing in step SA5 will be described with reference to the flowchart in FIG. **10**.

In alignment-degree calculation processing, first, the corresponding-point-displacement calculation unit **51** calculates the degrees of misalignment of corresponding points (corresponding feature points) between the base image and the reference image by using a known method, such as the optical flow (step SB1).

Next, in the evaluation score calculation unit **57** of the clustering processing unit **53**, the acceleration evaluation score calculation unit **61** calculates, from the degrees of misalignment calculated in step SB1, the acceleration between two adjacent feature points as an evaluation score (step SB2).

Next, the evaluation score filter processing unit **63** of the evaluation score calculation unit **57** applies a two-dimensional spatial filter to a group of the accelerations calculated in step SB2 (step SB3). This suppresses fluctuations in

acceleration caused by an error in the calculation of the degrees of misalignment in step SB1 and also enhances a sharp change in acceleration.

Next, the statistic calculation unit **65** of the abnormal region determination unit **59** performs statistical processing of the group of accelerations and calculates a statistic of the accelerations for each of the horizontal positions and for each of the vertical positions of the reference image (step SB4).

Next, the region determination unit **67** of the abnormal region determination unit **59** determines an abnormal region in the reference image on the basis of the statistics calculated in step SB4 and classifies the feature points on the basis of the determination (step SB5).

More specifically, in the region determination unit **67**, the horizontal position having the largest statistic of the accelerations is determined to be the boundary between an abnormal region and a non-abnormal region, and the vertical position having the largest statistic of the accelerations is determined to be the boundary between an abnormal region and a non-abnormal region, thus determining an abnormal region.

Subsequently, the region determination unit **67** classifies, into one of two sets, each of the plurality of feature points extracted by the optical flow, feature point matching, or the like in step SB1 depending on whether the feature point is a feature point contained in the abnormal region or is a feature point contained in a region other than the abnormal region (non-abnormal region). By doing so, the set composed of only feature points in the abnormal region and the set composed of only feature points in the non-abnormal region are produced.

Next, the multi-plane projection conversion matrix calculation unit **55** produces, from the feature points belonging to the set for the non-abnormal region classified in step SB5, at least one initial set composed of three or more feature points assumed to be located on the same plane and calculates a projection conversion matrix from the feature points contained in the initial set (step SB6). By doing so, the initial set, from which the feature points in the abnormal region are excluded, is produced. The projection conversion matrix calculated from such an initial set becomes a proper projection conversion matrix free from the influence of a disturbance like the moving object **S4**.

Subsequently, the multi-plane projection conversion matrix calculation unit **55** calculates the degrees of alignment  $dif\_x$  and  $dif\_y$  of each pixel in the reference image by using the projection conversion matrix (step SB7).

Then, in the image combining unit **31**, the generation of the combined image in step SA6 is performed on the basis of the calculated degrees of alignment  $dif\_x$  and  $dif\_y$ .

The accelerations of the movements of the subjects **S2** and **S3** between images due to a camera motion become substantially constant in the image, whereas the acceleration abruptly changes in a region in which a disturbance like the moving object **S4** is present. Therefore, a difference in acceleration arises between a feature point extracted from the region of the moving object **S4** and a feature point extracted from regions other than the region of the moving object **S4**.

According to the image acquisition system **100** and the image processing method including the image processing unit **9** according to this embodiment, when feature points are extracted from an abnormal region serving as a disturbance, the feature points in the abnormal region are detected on the basis of a sharp change in acceleration of the feature points. Then, an initial set composed of the other feature points that

have remained as a result of the feature points in the abnormal region being excluded is produced. By using such an initial set, a projection conversion matrix can be obtained correctly without suffering the influence of the disturbance. This makes it possible to generate a combined image in which an artifact due to misalignment is suppressed even in the case of the subjects **S2**, **S3**, and **S4** that have depths and in which a plurality of planes coexist.

Although this embodiment is configured so that the image processing method is realized by means of hardware, the image processing method may be realized by means of computer-executable image processing programs.

Although one embodiment of the present invention has been described in detail with reference to the drawings, the specific structures are not limited to those of this embodiment but include design changes etc. that do not depart from the spirit of the present invention. For example, this embodiment has been described by way of an example of the image acquisition system **100** serving as a digital camera. However, the image acquisition system **100** is not limited to a digital camera; the above-described technique is applicable, as long as a plurality of pieces of imaging data in which a base image and a reference image are present are available.

The above-described embodiment also leads to the following invention.

A first aspect of the present invention is an image processing device for generating a combined image by combining one base image and at least one reference image other than the base image that have been acquired time-sequentially, and the image processing device includes: an alignment-degree calculation unit for calculating the degree of alignment of each pixel of the reference image with respect to each pixel of the base image by using at least one projection conversion matrix; and an image combining unit for generating the combined image by converting the reference image on the basis of the degrees of alignment calculated by the alignment-degree calculation unit and by combining the converted reference image with the base image, wherein the alignment-degree calculation unit has a corresponding-region-displacement calculation unit for calculating a displacement of each of a plurality of corresponding feature regions between the reference image and the base image, a clustering processing unit for classifying, as at least one set, other feature regions excluding, from the plurality of feature regions, an abnormal feature region having the displacement that shows a different tendency from the displacement of the other feature regions, and a projection conversion matrix calculation unit for calculating the at least one projection conversion matrix by using the displacement of the other feature regions and the result of classification performed by the clustering processing unit, wherein the clustering processing unit has an evaluation score calculation unit for calculating an evaluation score of each of the plurality of feature regions by using the displacement calculated by the corresponding-region-displacement calculation unit and an abnormal region determination unit for determining the abnormal region on the basis of the evaluation score calculated by the evaluation score calculation unit, and wherein the evaluation score calculation unit has an acceleration evaluation score calculation unit for calculating, as the evaluation score, the difference value between the displacements of two feature regions adjacent to each other in at least one of the up/down direction, the left/right direction, and the oblique 45° direction.

According to the above-described first aspect, the alignment-degree calculation unit calculates, by using the projection conversion matrix, the degree of alignment for

aligning each of the pixels of the reference image with each of the pixels of the base image, and the image combining unit combines the reference image converted on the basis of the degrees of alignment with the base image. By doing so, a combined image free from misalignment of a subject is generated.

In this case, in the alignment-degree calculation unit, displacements of corresponding feature regions between the reference image and the base image are calculated by the corresponding-region-displacement calculation unit. The displacements of the feature regions caused by a motion of the image acquisition device for acquiring the base image and the reference image show tendencies substantially identical to one another. In contrast, the displacements of feature regions caused by a disturbance such as a moving object show different tendencies from the displacements of the other feature regions.

In the clustering processing unit, a feature region in which such a disturbance is occurring is preliminarily excluded as an abnormal region, thus producing a set composed of the feature regions other than the abnormal region. By using a set composed of such feature regions, the projection conversion matrix calculation unit can obtain a projection conversion matrix correctly. This makes it possible to generate a combined image in which an artifact due to misalignment is suppressed even in the case of subjects that have depths and in which a plurality of planes coexist.

In addition, by using evaluation scores based on displacements, the abnormal region can be easily determined.

In addition, the difference value between displacements calculated by the acceleration evaluation score calculation unit represents a change in moving speed, i.e., an acceleration, between two adjacent feature regions. By using such an acceleration as the evaluation score, the abnormal region can be detected with high accuracy.

In the above-described first aspect, the evaluation score calculation unit may have an evaluation score filter processing unit for applying filter processing to the calculated evaluation score. It is preferable that filter processing applied by the evaluation score filter processing unit be edge enhancement filter processing or edge-retaining smoothing filter processing, in which an edge enhancement filter and a noise reduction filter are combined.

By doing so, changes in evaluation scores based on a disturbance are emphasized, compared with changes in evaluation scores based on a factor other than the disturbance. Therefore, the abnormal region can be determined more correctly on the basis of the evaluation scores subjected to filter processing.

In the above-described first aspect, the abnormal region determination unit may have a statistic calculation unit for calculating a statistic of the evaluation scores calculated by the evaluation score calculation unit and a region determination unit for determining the abnormal region on the basis of the statistic calculated by the statistic calculation unit.

By doing so, the abnormal region can be determined even more correctly on the basis of the statistics calculated from the evaluation scores.

In the above-described first aspect, the statistic calculation unit may calculate, as the statistic for each horizontal position and each vertical position in the reference image, at least one of the mean value, the median value, the integrated value, the maximum value, and the minimum value of the evaluation scores calculated by the evaluation score calculation unit.

By doing so, the horizontal position and the vertical position of the abnormal region in the reference image can be determined on the basis of statistics.

In the above-described first aspect, the region determination unit may determine that a horizontal position and a vertical position in the reference image, the horizontal position and vertical position having the statistic that is equal to or larger than a predetermined threshold value, are a boundary between the abnormal region and a non-abnormal region other than the abnormal region. Alternatively, the region determination unit may calculate the difference between the statistics of two horizontal positions adjacent to each other and the difference between the statistics of two vertical positions adjacent to each other and may determine that a region between the two horizontal positions and a region between the two vertical positions in which the calculated differences between the statistics are equal to or larger than a predetermined threshold value is a boundary between the abnormal region and a non-abnormal region serving as the other feature region.

The statistic sharply changes between the abnormal region and the non-abnormal region. Therefore, the boundary between the abnormal region and the non-abnormal region can be accurately determined on the basis of the magnitude of a statistic or the difference of statistic between two adjacent positions.

A second aspect of the present invention is an image processing method for generating a combined image by combining one base image and at least one reference image other than the base image that have been acquired time-sequentially, and the image processing method includes: an alignment-degree calculation step for calculating the degree of alignment of each pixel of the reference image with respect to each pixel of the base image by using at least one projection conversion matrix; and an image combining step for generating the combined image by converting the reference image on the basis of the degrees of alignment calculated in the alignment-degree calculation step and by combining the converted reference image with the base image, wherein the alignment-degree calculation step includes a corresponding-region-displacement calculation step for calculating a displacement of each of a plurality of corresponding feature regions between the reference image and the base image, a clustering processing step for classifying, as at least one set, other feature regions excluding, from the plurality of feature regions, an abnormal feature region having the displacement that shows a different tendency from the displacement of the other feature regions, and a projection conversion matrix calculation step for calculating the at least one projection conversion matrix by using the displacement of the other feature regions and the result of classification executed in the clustering processing step.

A third aspect of the present invention is an image processing program for causing a computer to execute processing for generating a combined image by combining one base image and at least one reference image other than the base image that have been acquired time-sequentially, and the program causes the computer to execute: an alignment-degree calculation step for calculating the degree of alignment of each pixel of the reference image with respect to each pixel of the base image by using at least one projection conversion matrix; and an image combining step for generating the combined image by converting the reference image on the basis of the degrees of alignment calculated in the alignment-degree calculation step and by combining the converted reference image with the base image, wherein the alignment-degree calculation step includes a

corresponding-region-displacement calculation step for calculating a displacement of each of a plurality of corresponding feature regions between the reference image and the base image, a clustering processing step for classifying, as at least one set, other feature regions excluding, from the plurality of feature regions, an abnormal feature region having the displacement that shows a different tendency from the displacement of the other feature regions, and a projection conversion matrix calculation step for calculating the at least one projection conversion matrix by using the displacement of the other feature regions and the result of classification executed in the clustering processing step.

REFERENCE SIGNS LIST

- 9 Image processing unit (image processing device)
- 29 Alignment-degree calculation unit
- 31 Image combining unit
- 51 Corresponding-point-displacement calculation unit (corresponding-region-displacement calculation unit)
- 53 Clustering processing unit
- 55 Multi-plane projection conversion matrix calculation unit (projection conversion matrix calculation unit)
- 57 Evaluation score calculation unit
- 59 Abnormal region determination unit
- 61 Acceleration evaluation score calculation unit
- 63 Evaluation score filter processing unit
- 65 Statistic calculation unit
- 67 Region determination unit
- 100 Image acquisition system
- SA5 Alignment-degree calculation step
- SA6 Image combining step
- SB1 Corresponding-region-displacement calculation step
- SB2, SB3, SB4, SB5 Clustering processing step
- SB6 Multi-plane projection conversion matrix calculation step

The invention claimed is:

1. An image processing device for generating a combined image by combining one base image and at least one reference image other than the base image that have been acquired time-sequentially, comprising:  
 circuitry configured to:  
 calculate a degree of alignment of each pixel of the reference image with respect to a corresponding pixel of the base image by using at least one projection conversion matrix; and  
 generate the combined image by converting the reference image based on the calculated degree of alignment and by combining the converted reference image with the base image,  
 wherein in the calculating of the degree of alignment, the circuitry is configured to:  
 calculate a displacement of each of a plurality of corresponding feature regions between the reference image and the base image;  
 classify, as at least one set, other feature regions excluding, from the plurality of feature regions, an abnormal feature region having the displacement that shows a different tendency from the displacement of the other feature regions; and  
 calculate the at least one projection conversion matrix by using the displacement of the other feature regions and a result of the classifying the other feature regions,  
 wherein in the classifying the other feature regions, the circuitry is configured to:

calculate an evaluation score of each of the plurality of feature regions by using the calculated displacement; and  
 determine the abnormal region based on the calculated evaluation score, and  
 wherein in the calculating the evaluation score, the circuitry is configured to:  
 calculate, as the evaluation score, a difference value between the displacements of two feature regions adjacent to each other in at least one of an up/down direction, a left/right direction, and an oblique 45° direction; and  
 apply filter processing to the calculated evaluation score.  
 2. The image processing device according to claim 1, wherein in the applying the filter processing, the circuitry is configured to apply edge enhancement filter processing or edge-retaining smoothing filter processing in which an edge enhancement filter and a noise reduction filter are combined.  
 3. The image processing device according to claim 1, wherein in the determining the abnormal region, the circuitry is configured to:  
 calculate a statistic of the calculated evaluation scores; and  
 determine the abnormal region based on the calculated statistic.  
 4. The image processing device according to claim 3, wherein in the calculating the statistic, the circuitry is configured to calculate, as the statistic for each horizontal position and each vertical position in the reference image, at least one of a mean value, a median value, an integrated value, a maximum value, and a minimum value of the calculated evaluation scores.  
 5. The image processing device according to claim 3, wherein in the determining the abnormal region, the circuitry is configured to determine that a horizontal position and a vertical position in the reference image, the horizontal position and vertical position having the statistic that is equal to or larger than a predetermined threshold value, are a boundary between the abnormal region and a non-abnormal region other than the abnormal region.  
 6. The image processing device according to claim 4, wherein in the determining the abnormal region, the circuitry is configured to calculate a difference between the statistics of two horizontal positions adjacent to each other and the difference between the statistics of two vertical positions adjacent to each other and determine that a region between the two horizontal positions and a region between the two vertical positions in which the calculated differences between the statistics are equal to or larger than a predetermined threshold value is a boundary between the abnormal region and a non-abnormal region other than the abnormal region.  
 7. An image processing method for generating a combined image by combining one base image and at least one reference image other than the base image that have been acquired time-sequentially, comprising:  
 calculating a degree of alignment of each pixel of the reference image with respect to a corresponding pixel of the base image by using at least one projection conversion matrix; and  
 generating the combined image by converting the reference image based on the calculated degrees of alignment and by combining the converted reference image with the base image,

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wherein in the calculating of the degree of alignment:  
 calculating a displacement of each of a plurality of  
 corresponding feature regions between the reference  
 image and the base image;  
 classifying, as at least one set, other feature regions  
 excluding, from the plurality of feature regions, an  
 abnormal feature region having the displacement  
 that shows a different tendency from the displace-  
 ment of the other feature regions; and  
 calculating the at least one projection conversion  
 matrix by using the displacement of the other feature  
 regions and a result of the classifying the other  
 feature regions,  
 wherein in the classifying the other feature regions:  
 calculating an evaluation score of each of the plurality  
 of feature regions by using the calculated displace-  
 ment; and  
 determining the abnormal region based on the calcu-  
 lated evaluation score, and  
 wherein in the calculating the evaluation score:  
 calculating, as the evaluation score, a difference value  
 between the displacements of two feature regions  
 adjacent to each other in at least one of an up/down  
 direction, a left/right direction, and an oblique 45°  
 direction; and  
 applying filter processing to the calculated evaluation  
 score.

8. A non-transitory computer-readable medium having  
 stored thereon an image processing program for causing a  
 computer to execute processing for generating a combined  
 image by combining one base image and at least one  
 reference image other than the base image that have been  
 acquired time-sequentially, the program causing the com-  
 puter to execute functions of:

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calculating a degree of alignment of each pixel of the  
 reference image with respect to a corresponding pixel  
 of the base image by using at least one projection  
 conversion matrix; and  
 generating the combined image by converting the refer-  
 ence image based on the calculated degrees of align-  
 ment and by combining the converted reference image  
 with the base image,  
 wherein in the calculating of the degree of alignment:  
 calculating a displacement of each of a plurality of  
 corresponding feature regions between the reference  
 image and the base image;  
 classifying, as at least one set, other feature regions  
 excluding, from the plurality of feature regions, an  
 abnormal feature region having the displacement  
 that shows a different tendency from the displace-  
 ment of the other feature regions; and  
 calculating the at least one projection conversion  
 matrix by using the displacement of the other feature  
 regions and a result of the classifying the other  
 feature regions,  
 wherein in the classifying the other feature regions:  
 calculating an evaluation score of each of the plurality  
 of feature regions by using the calculated displace-  
 ment; and  
 determining the abnormal region based on the calcu-  
 lated evaluation score, and  
 wherein in the calculating the evaluation score:  
 calculating, as the evaluation score, a difference value  
 between the displacements of two feature regions  
 adjacent to each other in at least one of an up/down  
 direction, a left/right direction, and an oblique 45°  
 direction; and  
 applying filter processing to the calculated evaluation  
 score.

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